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16. ABSTRACT The manual summarizes information that will aid in identifying and controlling release hazards specific to the South Coast Air Quality Management District (SCAQMD) of southern California. The SCAQMD has been considering a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy, which will serve as a guide to industry and communities, includes monitoring activities associated with the storage, handling, and use of certain chemicals. Carbon tetrachloride has an immediately dangerous to life and health (IDLH) concentration of 300 ppm, making it a moderate acute toxic hazard. To reduce the risk associated with an accidental release of carbon tetrachloride, the potential causes of releases from processes using carbon tetrachloride in the SCAQMD must be identified. Such measures include recommendations on: plant design practices; prevention, protection, and mitigation technologies; and operation and maintenance practices. Conceptual costs of possible prevention, protection, and mitigation measures are estimated.

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Carbon Tetrachloride	Stationary Sources	07C
Emission	Accidental Releases	14G
Accidents		13L
Toxicity		06T
Storage		15E
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PREVENTION REFERENCE MANUAL: CHEMICAL SPECIFIC VOLUME 6: CONTROL OF ACCIDENTAL RELEASES OF CARBON TETRACHLORIDE (SCAQMD)

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ABSTRACT

The South Coast Air Quality Management District (SCAQMD) of southern California has developed a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring the storage, handling, and use of certain chemicals and providing guidance to industry and communities. This manual summarrizes technical information that will assist in identifying and controlling release hazards specific to the SCAQMC associated with carbon tetrachloride.

Carbon tetrachloride has an IDLH (Immediately Dangerous to Life and Health) concentration of 300 ppm and is a suspected human carcinogen. Reducing the risk associated with an accidental release of carbon tetrachloride involves identifying some of the potential causes of accidental releases in processes that use carbon tetrachloride in the SCAQMD. In this manual, examples of potential causes are identified, as are specific measures that may be taken to reduce the accidental release risk. Such measures include recommendations on plant design practices, prevention, protection and mitigation technologies, and operation and maintenance practices. Conceptual cost estimates of possible prevention, protection, and mitigation measures are provided.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

Recognizing the risk associated with accidental releases of air toxics in southern California, the South Coast Air Quality Management District (SCAQMD), which includes Los Angeles, Orange, San Bernadino, and Riverside Counties, conducted a study in 1985 to determine the presence, quantities, and uses of hazardous chemicals in the SCAQMD. The SCAQMD study resulted in a report, "South Coast Air Basin Accidental Toxic Air Emissions Study," that outlined an overall strategy for reducing the potential for a major toxic chemical release incident.

The strategy includes monitoring industry activities associated with the storage, handling, and use of certain chemicals; using the best technical information available; and guiding industry and communities in minimizing the potential for accidental releases and the consequences of any releases that might occur.

Historically, there do not appear to have been any significant releases of carbon tetrachloride in the SCAQMD. Major incidents elsewhere involving carbon tetrachloride have not been common.

1.2 PURPOSE OF THIS MANUAL

This manual compiles technical information on carbon tetrachloride and on the prevention of accidental releases of carbon tetrachloride. The manual addresses and summarizes issues relating to release prevention associated with the storage and handling of carbon tetrachloride and with process operations involving carbon tetrachloride as it is used in the SCAQMD.

This manual is not a specification manual, and in fact refers the reader to technical manuals and other sources for more complete information on the topics discussed. Other sources include manufacturers and distributors of carbon tetrachloride, and technical literature on design, operation, and loss prevention in facilities handling toxic chemicals.

1.3 USES OF CARBON TETRACHLORIDE

Carbon tetrachloride is commercially manufactured by the chlorination of carbon disulfide or by the chlorination of hydrocarbons at pyrolytic temperatures. Currently, its primary applications include chlorofluorocarbon production, grain fumigation, and use as a reaction medium. In the past it has been used for metal degreasing, as a dry cleaning agent, and as a fire-extinguisher agent. However, because of its suspected carcinogenicity, it has been replaced by other chlorinated hydrocarbons in some of these applications. Numerous references in the technical literature describe the manufacture and uses of carbon tetrachloride. It appears that in the SCAQMD, carbon tetrachloride is not manufactured; however, limited survey data indicate that the predominant uses of carbon tetrachloride in the SCAQMD are (1):

- As a reactant in chlorofluorocarbon manufacture; and
- As a solvent in the chlorination of paraffins.

Other uses for carbon tetrachloride could not be identified from the available survey data.

Storage of carbon tetrachloride includes railroad tank cars used for stationary storage and bulk storage tanks.

1.4 ORGANIZATION OF THE MANUAL

Following the introductory section, the remainder of the manual presents technical information on specific hazards and categories of hazards and their control as they relate to carbon tetrachloride.

Section 2 discusses physical, chemical, and toxicological properties of carbon tetrachloride. Section 3 describes the types of facilities that use carbon tetrachloride in the SCAQMD and process hazards associated with these facilities. Hazard prevention and control are discussed in Section 4, as are the costs of example storage and process facilities that reflect different levels of control through alternative systems. The examples are for illustration only and do not necessarily represent a satisfactory alternative control option in all cases. Section 5 contains references. Appendix A is a glossary of key technical terms that might not be familiar to all users of the manual, and Appendix B presents selected conversion factors between metric (SI) and English measurement units.

SECTION 2
CHEMICAL CHARACTERISTICS

This section of the report describes the physical, chemical, and toxicological properties of carbon tetrachloride as they relate to accidental release hazards.

2.1 PHYSICAL PROPERTIES

Carbon tetrachloride, at room temperature and pressure, is a colorless, nonflammable liquid with a characteristic nonirritant odor. Some of its common physical properties are listed in Table 2-1.

Carbon tetrachloride is a relatively nonpolar compound only slightly soluble in water. It is, however, soluble in alcohol and acetone, and miscible in benzene, chloroform and ether (2). In addition, carbon tetrachloride is more dense than water and large spills in water may settle before being totally dispersed, emulsified or volatilized.

Since carbon tetrachloride has a relatively high evaporation rate, spills and leaks can result in hazardous releases to the environment. In addition, since the density of carbon tetrachloride vapor is considerably greater than that of air, it will remain close to the ground and could create a potentially dangerous situation for workers and surrounding communities.

Because carbon tetrachloride has a large coefficient of expansion, expanding approximately 5 percent when warmed from 68°F to 140°F, liquid-full equipment presents a special hazard (2). A liquid-full vessel is a full vessel that is not vented and that has little or no vapor space present above the liquid. A liquid-full line is a section of pipe sealed off at both ends full of carbon tetrachloride, with little or no vapor space. In such cases,

TABLE 2-1. PHYSICAL PROPERTIES OF CARBON TETRACHLORIDE

		Reference
CAS Registry Number	07782-50-5	
Chemical Formula	CCl_4	
Molecular Weight	153.82	
Normal Boiling Point	170.1 °F @ 14.7 psia	2
Melting Point	-9.26 °F	2
Liquid Specific Gravity (H_2O = 1)	1.595 @ 68 °F	2
Vapor Specific Gravity (air = 1)	5.32 @ 68 °F	3
Vapor Pressure	1.74 psia @ 60 °F	3
Vapor Pressure Equation		4

$$\log Pv = A - \frac{B}{T+C}$$

where: Pv = vapor pressure, mmHg
T = temperature, °C
A = 6.87926, a constant
B = 1,212.021, a constant
C = 226.41, a constant

Liquid Viscosity	0.965 centipoise	2
Solubility in Water	800 ppm	3
Specific Heat at Constant Pressure (Liquid)	0.206 Btu/(lb-°F) @ 68 °F	2

(Continued)

TABLE 2-1 (Continued)

		Reference
Latent Heat of Vaporization	83.8 Btu/lb	2
Liquid Surface Tension	26.77 dynes/cm @ 68 °F	2
Average Coefficient of Thermal Expansion, 0-104 °F	0.00124/°F	2
Autoignition Temperature	>1,800 °F	2
Flash Point	None	2
Additional properties useful in determining other properties from physical property correlations:		
Critical Temperature	541.8 °F	2
Critical Pressure	45.4 atm	2
Critical Density	34.8 lb/ft^3	2
Energy of Molecular Interaction	327 K	5
Effective Molecular Diameter	5.881 Angstroms	5

there is no room for thermal expansion of the liquid and temperature increases can result in containment failure.

2.2 CHEMICAL PROPERTIES AND REACTIVITY

Carbon tetrachloride is the most toxic of the chloromethanes and is the most resistant to oxidation (2). Although it is non-flammable, when carbon tetrachloride is mixed with excess water and heated to 482 °F, it decomposes to carbon dioxide and hydrogen chloride (6). Hydrogen chloride formation is of concern because of the potential for corrosion of equipment and storage vessels (2). In addition, if the quantity of water is limited, carbon tetrachloride in contact with open fire or hot metal surfaces decomposes to produce highly toxic phosgene gas (2). Recognizing this thermal decomposition is of greatest importance when using carbon tetrachloride as a fire-extinguishing agent.

Carbon tetrachloride does not react with gaseous fluorine at ordinary temperatures; however, when hydrogen fluoride and carbon tetrachloride react together at a raised temperature and pressure, fluorine can replace one chlorine atom to produce a chlorofluorocarbon (2).

Dry carbon tetrachloride does not react with vessels and equipment constructed of iron and nickel. However, it does react slowly with copper and lead and can react violently with aluminum and its alloys (2). When carbon tetrachloride is dissolved in or is in contact with water, it will hydrolize at a slow but finite rate to produce highly corrosive hydrogen chloride. A small quantity of stabilizer is normally added to the carbon tetrachloride to prevent its decomposition. According to various literature sources, a number of compounds are effective as stabilizers (2).

2.3 TOXICOLOGICAL AND HEALTH EFFECTS

The toxicological effects of carbon tetrachloride have been well documented, both through animal studies and from accidental human exposure (7,8).

The IDLH level (Immediately Dangerous to Life and Health) is 300 parts per million (ppm) for thirty minutes exposure. In general, exposures below the IDLH level result in no overt symptoms of illness (3). However, increased concentration levels or exposure times can cause serious and often fatal injuries. Table 2-2 summarizes some of the relevant exposure limits for carbon tetrachloride. Table 2-3 summarizes observed human health effects of exposure to various concentrations of carbon tetrachloride (6).

Inhalation of carbon tetrachloride vapor is a primary hazard (2). Symptoms of exposure include nausea and vomiting, headache, burning eyes, throat, drowsiness, abdominal pain, and weakness. Prolonged or repeated exposure may result in chronic poisoning. In most poisonings, kidney and liver damage occur, along with respiratory paralysis and circulatory failure, often resulting in death (3,8). Carbon tetrachloride is also absorbed through the skin, but at a much slower rate than by inhalation. Prolonged and repeated exposure may cause dermatitis, cracking of the skin, and danger of secondary infection (2).

The carcinogenicity of carbon tetrachloride has been well-documented by both the International Agency for Research on Cancer and the National Cancer Institute, who identify it as an animal carcinogen (2). It is also a suspected human carcinogen (2).

TABLE 2-2. EXPOSURE LIMITS FOR CARBON TETRACHLORIDE

Exposure Limit	Concentration (ppm)	Description	Reference
IDLH	300	The concentration defined as posing an immediate danger to life and health (i.e. causes irreversible toxic effects for a 30-minute exposure).	9
PEL	10	A time-weighted 8-hour exposure to this concentration as set by the Occupational Safety and Health Administration (OSHA), should result in no adverse effects for the average worker.	4
LC_{Lo}	1,000	This concentration is the lowest published lethal concentration for a human over a 30- minute exposure.	4
TC_{Lo}	20	This concentration is the lowest published concentration causing toxic effects (irritation) for a 1-minute exposure.	4

TABLE 2-3. OBSERVED HUMAN HEALTH EFFECTS OF EXPOSURE TO VARIOUS CONCENTRATIONS[a]

ppm	Predicted Effect
10-11	Tolerated for 3 hours without abnormal reaction
49	Tolerated for 70 minutes without abnormal reaction
76	Tolerated for 2.5-4 hours without abnormal reaction
158	After 30 minutes, nervousness, nausea, rapid pulse and respiration
317	After 30 minutes, nausea, later vomiting, headache, rapid pulse and respiration
1,191	After 10 minutes, headache, nausea, vomiting, rapid pulse
2,380	After 5 minutes, dizziness, headache, sleepiness, rapid pulse
3,180	No effect after 2 and 5 minutes
4,770	After 5 minutes, slight somnolence
6,360	After 3 minutes, heaviness, paresthesias, slight somnolence, after exposure moderate pressure in head, moderate signs of intoxication
8,745	After 2 minutes, tinnitus, numbness of lips; after exposure salivation, paresthesias, vestigo, and slight somnolence
4,540	After 1 minute, paresthesias, numbness of lips, salivation, weakness, after 1-1/3 minutes, moderate fainting; after exposure slurred speech, 3 minutes later tinitus and after additional 2 minute euphoria

(Continued)

[a]These health effects are sometimes contradictory because they are based on actual case histories.

TABLE 2-3 (Continued)

ppm	Predicted Effect
10,000-13,000	Tolerated for 0.5-1 hour without immediate or late effects
14,151	Immediate paresthesias, followed by loss of consciousness, marked irritation, tinitus, euphoria, moderate headache
25,000-32,000	Dangerous with exposure for 0.5-1 hours
50,000	Fatal after exposure for 5-10 minutes

Source: Adapted from Reference 6.

SECTION 3
FACILITY DESCRIPTIONS AND PROCESS HAZARDS

This section briefly describes the uses of carbon tetrachloride in the SCAQMD and highlights major process hazards related to accidental releases. Preventive measures associated with these hazards are discussed in Section 4.

3.1 PROCESSING

Survey data indicate that the primary uses for carbon tetrachloride in the SCAQMD are as a reactant for chlorofluorocarbon manufacture and as a solvent for batch photochemical chlorination. This subsection summarizes the major technical features of typical processing and storage facilities found in the SCAQMD, and discusses accidental release hazards associated with these facilities.

3.1.1 Manufacture of Chlorofluorocarbons

A major use of carbon tetrachloride in the SCAQMD is in the manufacture of chlorofluorobcarbons. One commercially important method of production is the successive replacement of chlorine in chlorinated hydrocarbon feedstocks (chlorocarbons) by fluorine, using hydrogen fluoride as a source of fluorine. Figure 3-1 is a block diagram of a typical liquid phase chlorofluorocarbon manufacturing process.

The liquid-phase reaction system for the manufacture of chlorofluorocarbons consists of a heated reaction vessel containing catalyst dissolved in carbon tetrachloride, and partially fluorinated intermediates recycled to the reactor from downstream processing. Antimony pentafluoride or a mixture of antimony trifluoride and chlorine is typically used as catalyst (2,10). Liquid hydrogen fluoride and carbon tetrachloride are fed to the reactor. The carbon tetrachloride is first dried to remove any water that may be present to

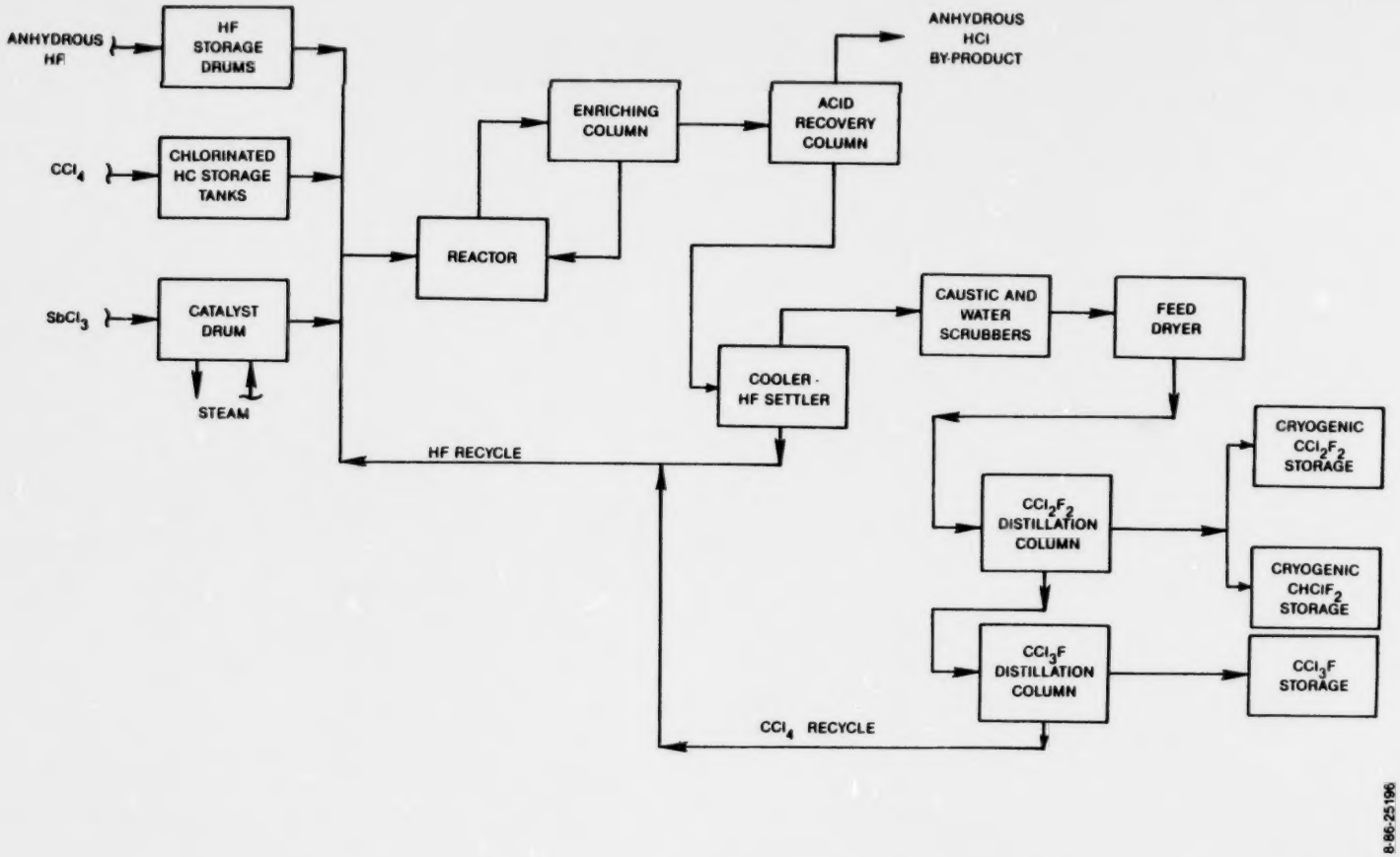

Figure 3-1. Conceptual diagram of typical fluorochlorocarbon process.

prevent corrosive hydrofluoric acid from forming in the system. The reactor typically operates at a temperature and pressure of approximately 176 °F and 100 psig, respectively (10). Although the fluorination reactions are exothermic, additional heat is added to the reactor because the reactor also serves as a reboiler for an enriching column. Crude product vapors evolved from the reactor are fed directly to the enriching column. The column is positioned so that the liquid bottoms flow by gravity as recycle to the reactor.

After being withdrawn from the enriching column, a stream containing hydrogen chloride, hydrogen fluoride, and the chlorofluorocarbon products is sent to an acid recovery column, which typically operates at approximately 100 psig (10). Hydrogen chloride is concentrated at the top of the column and is recovered as a by-product. The bottoms contain the product fluorocarbons and residual hydrogen fluoride at a temperature of approximately 122 °F (10). The hydrogen fluoride is removed in a hydrogen fluoride settler and is recycled to the reactor system.

Trace impurities are removed from the fluorocarbon products by scrubbing with water and a dilute caustic solution. Following the scrubbing operations, the product stream is dried and fractionated into various chlorofluorocarbon products.

Critical areas in the chlorofluorocarbon manufacturing process, excluding bulk storage and transfer (discussed in Section 3.3), include the following:

- Feed treatment to remove water from the carbon tetrachloride feed stream;
- Reactor; and
- Carbon tetrachloride recycle stream.

The feed treatment process to remove water is a critical area because water promotes corrosion. In the presence of moisture, carbon tetrachloride

can decompose to form highly corrosive hydrogen chloride which rapidly attacks many materials, including carbon steel. A properly designed system should use construction materials that take this corrosion potential into account and allow a certain moisture concentration to be maintained. Deficiencies or failures in the water removal system could lead to a protracted corrosion problem, resulting eventually in equipment failure.

An exothermic reactor is used in the chlorofluorocarbon process, but since it also serves as a reboiler to an enriching column, a reactor cooling system is not required for heat removal. In fact, additional heat is added. A potential hazard is overheating and overpressure caused by a malfunction in the temperature control system.

The carbon tetrachloride recycle stream presents the hazards of vessel, piping valve, and pump failure from potential corrosion caused by a buildup of trace quantities of water in the system.

3.1.2 Photochemical Chlorination

Photochemical chlorination is a process using ultraviolet light as the energy source for carrying out the reaction between chlorine and a hydrocarbon feedstock. Photochemical reactors can be batch or continuously operated. In batch operations, the reaction is carried out in a process solvent such as carbon tetrachloride. Figure 3-2 shows an example of a typical batch reactor. A batch reactor consists of a large, stirred jacketed vessel with lamps inserted through the top. The lamps are usually blanketed and water cooled.

Critical areas in this process include:

- Cooling of reactor or lamps;
- Agitation of reactants; and
- Seals on the reactor head or stirrer shaft.

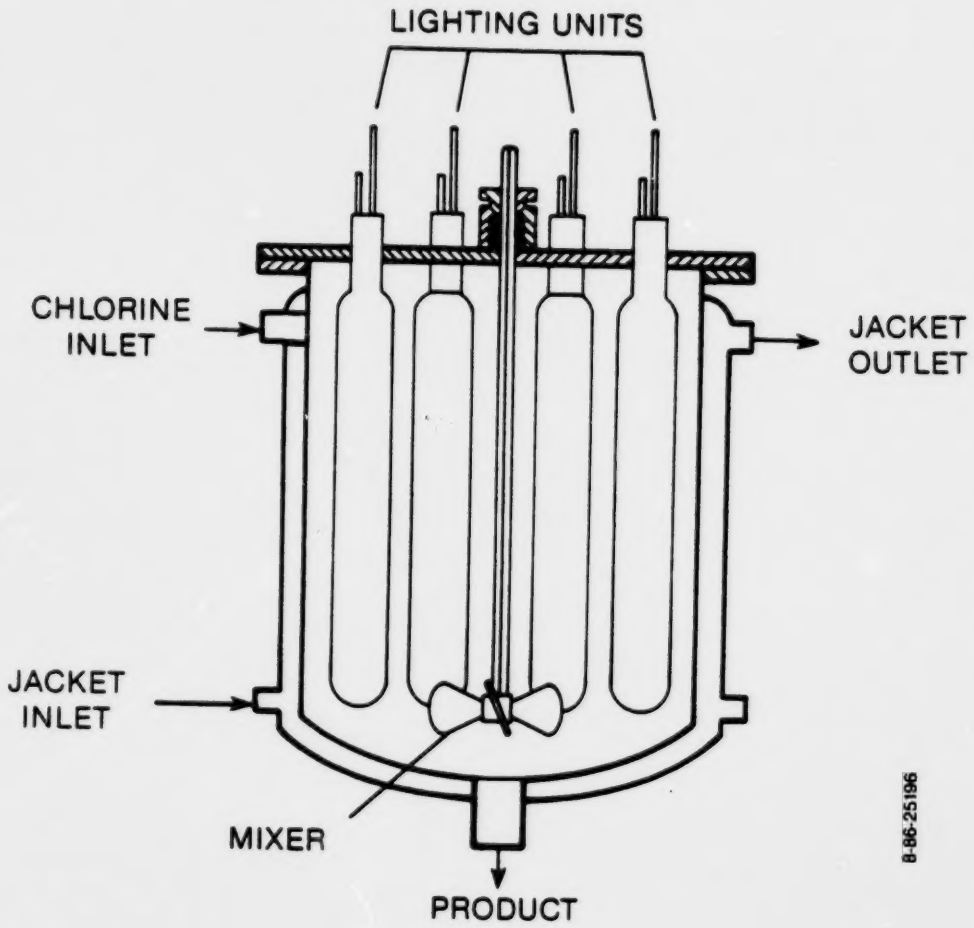

Figure 3-2. Batch photochlorination reactor.

From the perspective of a carbon tetrachloride release, a negative characteristic of the batch photochemical chlorination process is the use of carbon tetrachloride as a solvent rather than as a reactant. This means that in the chlorination process the carbon tetrachloride is present in high concentrations and the possibility of a release is greater than might exist in a process where it is consumed as a reactant.

A failure of the cooling system or agitation in the batch reactor could result in local overheating and lead to equipment failure. Finally, a failure in the reactor head or agitator seals could result in a release of carbon tetrachloride.

3.2 STORAGE AND TRANSFER

Carbon tetrachloride is stored in three types of storage vessels: fixed roof tanks, internal floating roof tanks, and pressure vessels (11). Carbon tetrachloride is also shipped and stored in tank cars and tank trucks.

The primary hazards associated with the storage of carbon tetrachloride are:

- Inadequate venting systems;
- Overheating; and
- Overfilling.

Atmospheric and low pressure storage vessels present an additional problem of carbon tetrachloride emissions from tank vents that can contribute to health and environmental problems if not controlled.

Transfer of carbon tetrachloride to storage is accomplished either by means of pumps or compressed inert gas pressure. If compressed inert gas is

is used, it is usually dried first to prevent corrosion of the storage and transfer vessels.

For safety reasons, pump transfer is commonly preferred over compressed gas transfer. The pumps most commonly used are centrifugal, rotary, positive displacement or seal-less, depending on the specific situation. In addition, self-priming pumps are commonly used since they can provide sufficient discharge pressure for transfer to distant or elevated storage areas, thus avoiding the hazards associated with dry gas priming of the pump.

3.3 POTENTIAL CAUSES OF RELEASES

Carbon tetrachloride can be used safely in appropriate processing and storage equipment; however, the potential exists for a hazardous release in any type of plant that handles this material. Possible sources of such a release are numerous. Large-scale releases may result from leaks or ruptures of large storage vessels, including tank cars on site, or from failure of process machinery such as pumps that maintain a large throughput of carbon tetrachloride. Smaller releases may result from ruptured lines, leaking valves, fittings, flanges, valve packing, or gaskets. Specific potential release sources within processes dominant in the SCAQMD were identified in the preceding subsection of this manual.

Failures leading to accidental releases may be broadly classified as due to process, equipment, or operational problems. Causes of releases discussed below are intended to be illustrative, not exhaustive.

3.3.1 Process Causes

Process causes are related to the fundamentals of process chemistry, control, and general operation. Possible process causes of a carbon tetrachloride release include:

- Backflow of chlorofluorocarbon process reactants to a carbon tetrachloride feed tank;

- Inadequate water removal from carbon tetrachloride and hydrocarbon feedstock feed in the chlorofluorocarbon process over a long period of time, leading to progressive corrosion;

- Excessive feeds in any part of the system, leading to overfilling or overpressuring equipment;

- Failure of cooling system to chlorination reactor; and

- Loss of condenser cooling to distillation units.

- Overheating in reactors or distillation units.

3.3.2 Equipment Causes

- Excessive stress due to improper material selection, fabrication, construction, or installation;

- Failure of vessels at normal operating conditions due to weakening of equipment from excessive stress, external loadings, or corrosion.

- Mechanical fatigue and shock in any equipment. Mechanical fatigue could result from age, vibration, or stress cycling, caused by pressure cycling, for example. Shock could occur from collisions with moving equipment such as cranes or other equipment in process or storage areas;

- Thermal fatigue and shock in reaction vessels, heat exchangers, and distillation columns;

- Brittle fracture in any equipment, but especially in carbon steel subjected to extensive corrosion. Equipment constructed of alloys, especially high-strength alloys selected to reduce the weight of major process equipment, might be especially sensitive where some corrosion has occurred, or where severe operating conditions are encountered;

- Creep failure in high temperature equipment subjected to extreme operational upsets, especially excess temperatures. This can occur in equipment subjected to a fire;

- All forms of corrosion, both internal and external.

3.3.3 Operational Causes

Operational causes of accidental releases are a result of incorrect procedures or human errors (i.e., not following correct procedures). These causes include:

- Overfilled storage vessels;

- Improper process system operation;

- Errors in loading and unloading procedures;

- Inadequate maintenance in general, but especially of water removal unit operations and pressure relief systems and other preventive and protective systems; and

- Lack of inspection and non-destructive testing of vessels and piping to detect corrosion weakening.

SECTION 4
HAZARD PREVENTION AND CONTROL

4.1 GENERAL CONSIDERATIONS

The prevention of accidental releases relies on a combination of technological, administrative, and operation practices that apply to the design, construction, and operation of facilities where carbon tetrachloride is stored and used. Considerations in these areas can be grouped as follows:

- Process design;
- Physical plant design;
- Operating and maintenance practices; and
- Protective systems.

Specific factors in each of these areas must be considered that could lead to a process upset or failure that could directly cause a release of carbon tetrachloride to the environment or result in an equipment failure that would then cause the release. Equipment and procedures should be examined to ensure that they are in accordance with applicable codes, standards, and regulations. In addition, stricter equipment and procedural specifications should be in place if extra protection against a release is considered appropriate.

The following subsections discuss specific considerations regarding release prevention; more detailed discussions will be found in the manual on control technologies, part of this manual series.

4.2 PROCESS DESIGN

Process design involves the fundamental characteristics of processes that use carbon tetrachloride. Any discussions of how process design may be involved in accidental chemical releases must include an evaluation of how deviations from expected process design conditions could initiate a series of events that result in an accidental release. The primary focus is on how the process is controlled in terms of the basic process chemistry involved, and on the variables of flow, pressure, temperature, composition, and level. Additional considerations may include quantity measuring systems, mixing systems, fire protection, and process control instrumentation. Modifications that enhance process integrity would involve changes in the quantities of materials, process pressure and temperature conditions, the unit operations, sequence of operations, the process control strategies, and the instrumentation used.

Table 4-1 shows the relationship between specific key process design considerations and the individual processes described in Section 3 of this manual. This does not mean that other factors should be ignored, nor does it mean that proper attention to the key considerations ensures a safe system. The factors in the table, however, must be properly addressed if a system is to be safe.

From the perspective of accidental release prevention, it is most important to prevent moisture from entering the system and to prevent systems containing carbon tetrachloride from overheating. Overheating is hazardous because it may lead to overpressure, which weakens process equipment and increases the potential for leaks to form at joints and valves. Wide temperature fluctuations also significantly decrease the life-span of many materials of construction. Careful monitoring of the moisture content is important to prevent the decomposition of carbon tetrachloride and the formation of highly corrosive hydrogen chloride.

TABLE 4-1. KEY PROCESS DESIGN CONSIDERATIONS FOR PROCESSES INVOLVING CARBON TETRACHLORIDE

Process Design Considerations	Process or Unit Operation
Contamination with water	All
Flow control of carbon tetrachloride feed	All
Temperature sensing and heating media flow control	Chlorofluorocarbon reactors, distillation column condensers
Adequate pressure relief	Storage tanks, reactors, distillation columns, heat exchangers
Mixing	Chlorination reactors
Corrosion monitoring	All, but especially recycle circuits
Temperature monitoring	Chlorination reactors, chlorofluorocarbon reactors, distillation column reboilers
Level sensing and control	Storage tanks, reactors

4.3 PHYSICAL PLANT DESIGN

Physical plant design considerations include equipment, sizing and layout, and transfer/transport facilities. Vessels, piping and valves, process machinery, instrumentation, and factors such as the location of systems and equipment must all be considered. The following subsections cover various aspects of physical plant design beginning with a discussion of construction materials.

4.3.1 Equipment

Materials of Construction--

Materials of construction for equipment used in carbon tetrachloride service must be chosen to minimize the possible decomposition of carbon tetrachloride. Table 4-2 presents a list of possible materials of construction for carbon tetrachloride service (12).

The proper selection of construction materials for carbon tetrachloride service is dictated by temperature and the presence of moisture. In the dry state, carbon tetrachloride can be stored in contact with many metal surfaces. However, on contact with water or heating in air, carbon tetrachloride decomposes to form highly corrosive hydrogen chloride. The decomposition rate increases with increasing temperature and contact with some metal surface (i.e., iron) (2).

Dry carbon tetrachloride does not react with most metals commonly used for constructing vessels and equipment, although it does react slowly with copper and lead (2). Carbon tetrachloride does react, sometimes explosively, with aluminum and its alloys (2).

In general, nickel and nickel-copper alloys are used at critical points of processing plants to minimize and control thermal decomposition of carbon tetrachloride.

TABLE 4-2. MATERIALS OF CONSTRUCTION FOR CARBON TETRACHLORIDE SERVICE

Material	For Wet or Dry CCl_4	For Dry CCl_4 Only
Asphaltic Resins	X	
Ceramic	X	
Copper		X
Epoxy Resins	X	
Fiber Reinforced Plastic (FRP)	X	
Furane Resins	X	
Glass	X	
Hastelloy B	X	
Hastelloy C	X	
Hastelloy D	X	
Inconel	X	
Iron, Cast		X
Iron, High Silicon	X	
Lead	X	
Monel	X	
Nickel	X	
Phenolic Resins	X	
Polyesters	X	
Polyvinyl Chloride, Unplasticized	X	
Saran	X	
Stainless Steel, Alloy 20	X	
Steel, Mild		X
Zirconium	X	
PolyTetrafluoroethylene	X	

Vessels--

A variety of storage and process vessels are used in carbon tetrachloride service. Examples include storage drums, atmospheric and low pressure storage tanks, chemical reactors, separation columns, and heat exchangers. Each type of vessel has certain specifications under various codes and standards that should to be adhered to in design and fabrication.

Storage vessels for carbon tetrachloride range in size from 55-gallon drums up to multi-ton tanks. Three types of tanks are used for carbon tetrachloride storage: fixed roof atmospheric tanks, internal floating roof atmospheric tanks and pressure vessels (11). Because of the relatively large inventories contained in carbon tetrachloride storage vessels, when considering accidental releases they represent one of the most hazardous parts of a carbon tetrachloride facility.

Specific release prevention considerations for vessels include: overpressure protection, vacuum protection, temperature control, and corrosion prevention.

Several methods for preventing overpressurization and underpressurization of carbon tetrachloride storage vessels are employed, depending on the type of vessel. Atmospheric storage tanks are protected from overpressure and underpressure by atmospheric vents and/or pressure vacuum valves. These systems allow air to enter or vapor to escape, depending on the situation. In addition, some tanks are equipped with internal floating roofs to allow for expansion and contraction.

Situations can arise in which an atmospheric tank is subjected to pressure or vacuum that it cannot withstand. Vent blockage and insufficient vent capacity are the two most common causes of atmospheric tank failure (13). A coarse wire mesh guard is usually provided over tank vent openings to prevent objects from entering the vent and plugging the line somewhere downstream.

However, the wire mesh guard can become plugged with an accumulation of debris (13).

Pressure vessels, including storage tanks, tank trucks, and rail cars are usually protected by pressure relief valves and/or rupture disks. The pressure relief valve is set to relieve slightly above the design working pressure of the vessel, but well below the maximum allowable working pressure. Although carbon tetrachloride is stored in low-pressure storage vessels, vessels designed to withstand internal pressures in the range of 0.5-15 psig, pressure relief valves are still needed to prevent possible rupture from overpressure.

Pressure relief valves and rupture discs are designed to prevent explosion by controlled release of overpressurized contents. These relief systems are usually sized for flashing liquid caused by:

- Fire exposure;
- Thermal expansion;
- Internal reaction/decomposition; and
- Excess supply rates.

Relief piping must be sized for adequate flow. To avoid direct discharge to the environment, an overflow tank might be provided for overpressurized liquid. If the possibility exists that overpressurizing may be caused by something besides liquid thermal expansion, or where there is no overflow receiver, the vessels should be relieved to either a point in the process that can handle the discharge flow, or to a vapor recovery system.

General considerations for preventing an accidental release from a storage vessel also apply to the design and use of process and reaction vessels. In the latter type of vessels, however, there is a greater degree of risk, since these containers are often exposed to more severe conditions of temperature and/or pressure than is a regular storage vessel.

Primary considerations for process and reaction vessels include:

- Materials of construction;
- Pressure relief devices;
- Temperature control;
- Overflow protection;
- Foundations and supports.

The chlorination and chlorofluorocarbon reactors represent possible sources of major releases since they contain a large portion of the carbon tetrachloride used in their respective processes. These reactors must, therefore, be constructed of appropriate materials.

The feed to the reactors must be dry since moisture accelerates the corrosion rate of materials used in construction (e.g., carbon steel) (10). Provisions should be made for excluding moisture during any process shutdowns, or for purging the reactors at shutdown and before startups.

Piping--

As with carbon tetrachloride vessels, carbon tetrachloride pipework design must reflect the pressure, temperature, and corrosion concerns associated with use of the chemical. Careful attention must be paid to pipework and associated fittings since failures of this type of equipment are major contributors to accidental releases of chemicals. As with other hazardous chemicals, there are general guidelines for carbon tetrachloride piping systems. The first is simplicity of design; the number of joints and connections should be minimized. In addition to being securely supported, pipes should be sloped, with drainage at the low points. Piping should be constructed so as to allow for thermal expansion and should be protected from exposure to fire and high temperatures. Placement of valves should ensure isolation of leaking pipes and equipment.

The correct design and use of pipe supports is essential to reduce overstress and vibration that could lead to piping failure. The supports should be designed to handle the load associated with the pipe, operating and testing medium, insulation, and other equipment. Factors that must be considered include thermal expansion and contraction, vibrations caused by pumping and fluid flow, bending moments resulting from overpressure in the pipe, and external loads such as wind or ice accumulation.

All piping should be situated away from fire and fire hazards since the decomposition products could trigger an explosion. Piping carrying carbon tetrachloride should not be routed near other processes or piping networks that might present an external threat (e.g., piping carrying highly corrosive materials, high pressure processes). In addition, pipework should be protected from possible impact and other structural damage.

All types of valves are used in carbon tetrachloride service, including gate, globe, ball, relief, and check configurations. They must be constructed of material that does not promote the decomposition of carbon tetrachloride.

Process Machinery--

Process machinery refers to rotating or reciprocating equipment that may be used in the transfer or processing of carbon tetrachloride. This includes pumps and compressors used to move liquid or gaseous carbon tetrachloride where gas pressure padding is insufficient or inappropriate.

Pumps--Many of the concerns for carbon tetrachloride piping and valves also apply to pumps. To ensure that a given pump is suitable for a carbon tetrachloride service application, the system designer should obtain information from the pump manufacturer certifying that the pump will perform properly in this application.

Pumps should be constructed of materials that do not promote carbon tetrachloride decomposition at operating temperatures and pressures. They should be installed dry and oil-free. The pump's supply tank should have high- and low-level alarms; the pump should be interlocked to shut off at low

supply level or low discharge pressure. External pumps should be situated inside a diked area and should be accessible in the event of a tank leak.

In some situations, the potential for seal leakage rules out the use of rotating seals. Pump types that either isolate the seals from the process stream, or eliminate them altogether include canned-motor pumps, vertical extended-spindle submersible pumps, magnetically coupled pumps and diaphragm pumps (12).

Canned motor pumps are centrifugal units in which the motor housing is interconnected with the pump casing. Here, the process liquid actually serves as the bearing lubricant. An alternative concept is the vertical pump often used on storage tanks. These pumps consist of a submerged impeller housing connected by an extended drive shaft to the motor. The advantages of this arrangement are that the shaft seal is above the maximum liquid level (and is therefore not wetted by the pumped liquid) and the pump is self priming because the liquid is above the impeller.

Pumps using stuffing boxes and packing should be provided with double-packed seal chambers which can be purged with an appropriate inert fluid such as dry and oil-free nitrogen, or with a suitable seal liquid. The seal gas pressure should exceed the tank pressure by an appropriate margin. A seal fluid back-up system should be considered.

Magnetically-coupled pumps replace the drive shaft with a rotating magnetic field as the pump-motor coupling device. Diaphragm pumps are positive displacement units in which a reciprocating flexible diaphragm drives the fluid. This arrangement eliminates exposure of packing and seals to the pumped liquid. Because of the probability of eventual diaphragm failure, diaphragm pumps should be carefully considered in view of this hazard potential.

Improper operation of pumps as a result of cavitation, running dry, and deadheading can cause damage and failure of pumps. If cavitation is allowed

to occur, pitt and eventual serious damage to the impeller can result. Running a pump dry as a result of loss of head in a feed tank, for example, can seriously damage a pump. Finally, pumping against a closed valve can have serious ramifications. A pump bypass or kick-back are useful in avoiding such an occurrence. Failure of a pump, for whatever reason, can eventually lead to a hazardous release.

Centrifugal pumps often have a recycle loop back to the feed container that prevents overheating if the pump is deadheaded. Deadheading is also a concern with positive displacement pumps. To prevent rupture, positive displacement pumps commonly have a pressure relief valve that bypasses to the pump's suction.

Compressors--Reciprocating, centrifugal, liquid-ring rotary, and non-lubricated screw compressors are used with carbon tetrachloride. Details of such compressors are discussed in the technical literature (12).

Like pumps, compressors have the potential for heat buildup and shaft seal leakage. Heat sources in a compressor include the heat of compression as well as the heat generated through mechanical friction. Most multistaged compressors can be equipped with intercoolers that limit heat buildup and increase compressor efficiency by reducing the volume of gas going to the next compression stage. Both air and water cooling are used, but water systems must be designed to prevent leakage and contact of water with carbon tetrachloride.

While it is often possible to avoid using rotary shaft seals with carbon tetrachloride pumps, compressors in carbon tetrachloride service usually require seals such as double labyrinth seals. These seals have a series of interlocking tough points which, by creating many incremental pressure drops, reduce total leakage. Also, to further reduce leakage, dry air is injected into the seal. In the event of deadheading, a compressor discharge can have a pressure relief mechanism that vents to the compressor inlet, vapor recovery system, or incinerator. The inlet vent system appears to be satisfactory for

a short term downstream flow interruption. Where a sustained interruption might occur, relief to a recovery system or to an incinerator would be safer. Positive displacement compressors and pumps must always be equipped with overpressure relief as close to the discharge as possible (non-isolatable).

4.3.2 Plant Siting and Layout

The siting and layout of a particular facility using carbon tetrachloride is a complex issue requiring careful consideration of numerous factors, including: other processes in the area, the proximity of population centers, prevailing winds, local terrain, and potential natural external effects such as flooding. The rest of this subsection describes general principles that might apply to the siting and layout of carbon tetrachloride facilities.

Facilities or individual equipment items should be situated to reduce personnel exposure, both plant and public, in the event of a release. Since there are also other siting considerations, there may be trade-offs between this requirement and others in a process, some directly safety related. Siting should provide ready ingress or egress in the event of an emergency and yet take advantage of barriers, either man made or natural that could reduce the hazards of releases. Large distances between large inventories and sensitive receptors is desirable.

Layout refers to the placement and arrangement of equipment in the process facility. Various techniques available for formally assessing plant layout should be considered when planning high hazard facilities (13).

Following are general layout considerations:

- Large inventories of carbon tetrachloride should be kept away from sources of fire or explosion hazard.

- Vehicular traffic should not go too near carbon tetrachloride process or storage areas if this can be avoided.

- Where traffic is necessary, precautions should be taken to reduce the chances for vehicular collisions with equipment, especially pipe racks carrying carbon tetrachloride across or next to roadways.

- Carbon tetrachloride piping preferably should not be located adjacent to other piping that is under pressure or temperature, or that carries flammable materials.

- Storage facilities should be segregated from the main process unless the hazards of pipe transport are felt to outweigh the hazard of the storage tank for site-specific cases.

Because heat increases the decomposition of carbon tetrachloride and causes thermal expansion of liquid carbon tetrachloride, measures should be taken to situate piping, storage vessels, and other carbon tetrachloride equipment so that they are protected from heat sources. Hot process piping, equipment, steam lines, and other sources of direct or radiant heat should be avoided. Storage should also be situated away from control rooms, offices, utilities, storage and laboratory areas. Special precautions should be taken to keep carbon tetrachloride storage vessels away from potential fire or explosion sources.

In the event of an emergency, there should be multiple means of access to the facility for emergency vehicles and crews. Storage vessel shut off valves should be readily accessible. Containment for liquid storage tanks can be provided by diking. Dikes reduce evaporation while containing the liquid. It is also possible to equip a diked area to allow drainage to an underground containment sump, which would be vented to a vapor recovery system for safe discharge. A full containment system using a specially constructed building vented to a vapor recovery system is another possible option. This type of

secondary containment could be considered for large volume carbon tetrachloride tanks.

4.3.3 Transfer and Transport Facilities

Transfer and transport facilities where both road and rail tankers are loaded or unloaded are likely accident areas because of vehicle movement and the intermittent nature of the operations. Therefore, special attention should be given to the design of these facilities.

As mentioned in the previous section, tank car and tank truck facilities should be located away from sources of heat, fire, and explosion. Equipment in these areas should also be protected from impact by vehicles and other moving equipment. These tank vehicles should be securely moored during transfer operations; an interlock barrier system is commonly used. Sufficient space should be available to avoid congestion of vehicles or personnel during loading and unloading operations. Vehicles, especially trucks, should be able to move into and out of the area without reversing. High curbs around transfer areas and barriers around equipment should be provided to protect equipment from vehicle collisions.

When possible, carbon tetrachloride should be transferred via fixed rigid piping. In situations requiring flexible hoses or tubes, precautions must be taken to ensure sound connections. Flexible hoses must be constructed of materials resistant to carbon tetrachloride and must be designed to withstand the highest anticipated operating pressures. Avoiding cross contamination of chemical materials is also a concern. In addition, submerged transfer, the introduction of carbon tetrachloride into a vessel with the transfer line outlet below the liquid surface is used to minimize evaporation and release of carbon tetrachloride vapors. Vapor balance systems consisting of a pipeline between the vapor spaces of an unloading vessel and a carbon tetrachloride storage tank are commonly used to create an essentially closed system to minimize releases of carbon tetrachloride vapor.

4.4 PROTECTION TECHNOLOGIES

This subsection describes three types of protection technologies for containment and neutralization:

- Enclosures;
- Vapor recovery systems; and
- Incinerators.

4.4.1 Enclosures

Enclosures refer to containment structures that capture any carbon tetrachloride spilled or vented from storage or process equipment, thereby preventing immediate discharge of the chemical to the environment. The enclosures contain the spilled liquid or vapor until it can be transferred to other containment and discharged at a controlled rate that would not be injurious to people or to the environment, or transferred at a controlled rate to a vapor recovery or incineration system.

Specially designed enclosures for carbon tetrachloride storage or process equipment do not appear to be widely used. The idea that it may be preferable to locate toxic operations in the open air has been mentioned in the literature (13), as has the opposing idea that sometimes enclosures may be appropriate. The desirability of enclosure depends partly on the frequency with which personnel must be involved with the equipment. A common design rationale for not having an enclosure where toxic materials are used is to prevent the accumulation of toxic concentrations within enclosed areas. However, if the issue is providing secondary containment, total enclosure may be appropriate. Enclosures should be equipped with continuous monitoring equipment and alarms. Alarms should sound whenever lethal or flammable concentrations are detected.

Care must be taken when an enclosure is built around pressurized equipment. It would not be practical to design an enclosure to withstand the pressures associated with a sudden release of a pressurized vessel. An enclosure would probably fail because of the pressure created from such a release and could create an additional hazard. In these situations, it may be determined that an enclosure is not appropriate. If an enclosure is built around pressurized equipment, then it should be equipped with some type of explosion protection, such as rupture plates designed to fail before the entire structure fails.

The type of structures that appear suitable for carbon tetrachloride are concrete blocks, or concrete sheet buildings, or bunkers. An enclosure would have a ventilation system designed to draw in air when the building is vented to a vapor recovery or incineration system. The bottom section of the building used for stationary storage containers should be liquid tight to retain any carbon tetrachloride that might be spilled. Buildings around rail cars used for storage do not normally lend themselves easily to effective liquid containment. However, containment can be accomplished if the floor of the building is excavated several feet below the track level, while the tracks are supported at grade in the center.

While enclosures for secondary containment of carbon tetrachloride spills or release are not widely used, they can be considered for areas near sensitive receptors.

4.4.2 Vapor Recovery Systems

Vapor recovery is a method of recovering toxic materials from process streams. Common systems used are vapor-liquid absorption, compression, refrigeration, or vapor-solid absorption (14). These systems can control carbon tetrachloride releases from vents and pressure relief discharges, from process equipment, or from secondary containment enclosures.

Carbon tetrachloride discharges are commonly sent to a refrigerated vapor recovery unit or to a carbon absorption unit. If such a system is used to

protect against emergency releases, how it would be activated in time to respond to an emergency load must be considered. One approach used in some process facilities is to maintain the recovery unit in continuous operation. For many facilities, this would not be practical, and the system might be tied into a trip system to turn it on when it is needed.

4.4.3 Incineration

Incineration is a traditional method of destroying toxic vapor from process streams. Such devices can be used for controlling carbon tetrachloride releases from vents and pressure relief discharges, from process equipment, or from secondary containment enclosures.

Carbon tetrachloride discharges could be mixed with fuel and air in a thermal oxidation unit to convert the toxic vapor to hydrogen chloride. An additional problem arises in that hydrogen chloride is highly corrosive and thus the incineration system would have to be constructed of corrosion-resistant materials. Also, an acid-gas scrubber is needed to remove the hydrogen chloride from the vent gases before being released.

Considerations for activation in the event of an emergency load of hazardous vapor are the same as those associated with vapor recovery systems discussed above.

4.5 MITIGATION TECHNOLOGIES

If, in spite of all precautions, a large release of carbon tetrachloride occurs, the first priority is to rescue workers in the immediate vicinity of the accident and evacuate persons from downwind areas. The source of the release should be determined, and the leak should be plugged to stop the flow, if possible. The next primary concern becomes reducing the effects of the release on the plant and the surrounding community. Reducing the consequences of an accidental release of a hazardous chemical is referred to as mitigation. Mitigation technologies include such measures as physical barriers, water sprays and fogs, and foams, where applicable. The purpose of a mitigation

technique is to divert, limit, or disperse the chemical that has been spilled or released to the atmosphere to reduce the atmospheric concentration and the area affected by the chemical. In addition, secondary containment systems such as impounding basins, dikes, and flotation devices and/or foams are used to reduce the rate of evaporation from a spilled liquid. The mitigation technology chosen for a particular chemical depends on the specific properties of the chemical, including its flammability, toxicity, reactivity, and those properties that determine its dispersion characteristics in the atmosphere.

4.5.1 Secondary Containment System

Specific types of secondary containment systems include excavated basins, natural basins, earth, steel, or concrete dikes, and high impounding walls. The type of containment system best suited for a particular storage tank or process unit depends on the risk associated with an accidental release from that location. The inventory of carbon tetrachloride and its proximity to other portions of the plant and to the community should be considered when selecting a secondary containment system. The secondary containment system should be able to contain spills, with minimum damage to the facility and its surroundings and with minimum potential for escalating the event.

Secondary containment systems for carbon tetrachloride storage facilities commonly consist of one of the following:

- An adequate drainage system underlying the storage vessels that terminates in an impounding basin whose capacity is as large as that of the largest tank served.

- A diked area, with a capacity as large as that of the largest tank served.

These measures are designed to prevent the accidental discharge of carbon tetrachloride from spreading to uncontrolled areas.

The most common type of containment system is a low-wall dike surrounding one or more storage tanks. Generally, no more than three tanks are enclosed within one area because of the increased risk. Dike heights usually range from three to twelve feet, depending on the area available, to achieve the required volumetric capacity. The dike walls should be liquid tight and able to withstand the hydrostatic pressure and temperature of a spill. Low-wall dikes may be constructed of steel, concrete or earth. If earthen dikes are used, dike walls must be constructed and maintained to prevent leakage. Piping should be routed over dike walls, and penetrations through the walls should be avoided if possible. Vapor fences may be situated on top of the dikes to provide adequate vapor storage capacity. If there is more than one tank in the diked area, the tanks should be situated on berms above the maximum liquid level attainable in the impoundment.

A low-wall dike can effectively contain the liquid portion of an accidental release and keep the liquid from entering uncontrolled areas. By preventing the liquid from spreading, the low-wall dike can reduce the surface area of the spill. Reducing the surface area will reduce the rate of evaporation. The low-wall dike will partially protect the spill from wind, which can reduce the rate of evaporation. A dike with a vapor fence will provide extra protection from wind and will be even more effective at reducing the rate of evaporation.

A remote impounding basin is well-suited to storage systems where more than one tank is served and where a relatively large site is available. The flow from a carbon tetrachloride spill is directed to the basin by dikes and channels under the storage tanks that are designed to minimize exposure of the liquid to other tanks and to surrounding facilities. Because carbon tetrachloride evaporates at a relatively rapid rate, the trenches that lead to the remote impounding basin, as well as the basin itself, should be covered to reduce the rate of evaporation. Additionally, the impounding basin should be located near the tank to reduce the amount of carbon tetrachloride that evaporates as it travels to the basin.

This type of system has several advantages. The spilled liquid is removed from the immediate tank area, allowing access to the tank during the spill and reducing the probability that the spilled liquid will damage the tank, piping, electrical equipment, pumps or other equipment.

High-wall impoundments may be a viable secondary containment choice for selected systems. Circumstances that may warrant their use include limited storage site area, the need to minimize vapor generation rates, and/or the need to protect the tanks from external hazards. Maximum vapor generation rates will generally be lower for a high wall impoundment than for low wall dikes or remote impoundments because of the reduced surface contact area. These rates can be further reduced by using insulation on the wall and floor in the annular space. High impounding walls may be constructed of low temperature steel, reinforced concrete, or prestressed concrete. A weather shield may be provided between the tank and wall, with the annular space remaining open to the atmosphere. The available area surrounding the storage tank will dictate the minimum height of the wall. For high-wall impoundments, the walls may be designed with a volumetric capacity greater than that of the tank to contain vapors. Increasing the height of the walls also raises the elevation of any released vapor.

One disadvantage of these dikes is that the high walls around a tank may hinder routine external observation. Furthermore, the closer the wall is to the tank, the more difficult it becomes to reach the tank for inspection and maintenance. As with low-wall dikes, piping should be routed over the wall if possible. The closeness of the wall to the tank may necessitate placement of pumps outside of the wall, in which case the outlet (suction) lines will have to pass through the wall. In such a situation, a low dike encompassing the pipe penetrations and pumps may be provided, or a low dike may be placed around the entire wall.

One further type of secondary containment system is structurally integrated with the primary system and forms a vapor tight enclosure around the primary container. Many types of arrangements are possible. A double-walled

tank is an example of such an enclosure. These systems may be considered where protection of the primary container and containment of vapor for events not involving foundation or wall penetration failure are of greatest concern. Drawbacks of an integrated system are the greater complexity of the structure, the difficulty of access to certain components, and the fact that complete vapor containment cannot be guaranteed for all potential events.

Provisions should be made for draining rainwater from both impounding basins and diked areas, which will involve sumps and separate drainage pumps since direct drainage to storm-water sewers would presumably allow any spilled carbon tetrachloride to follow the same route. Alternately, a sloped rain hood may be used over the diked area, which could also serve to direct the rising vapors to a single release point (15). The ground within the enclosure should be graded to cause the spilled liquid to accumulate at one side or in one corner. This will decrease the area of ground to which the liquid is exposed and from which it may gain heat. In areas where it is critical to minimize vapor generation, surface insulation may be used in the diked area or impoundment to further reduce heat transfer from the environment to the spilled liquid. The floor of an impoundment may be sealed with a clay blanket to prevent the carbon tetrachloride from seeping into the ground; percolation into the ground causes the ground to cool more quickly, increasing the vapor generation rate.

4.5.2 Flotation Devices and Foams

Other possible means of reducing the surface area of spilled chemicals include placing impermeable flotation devices on the surface and applying foams.

Placing an impermeable flotation device over a spilled chemical is a direct and nearly 100 percent efficient approach for containing toxic vapors. However, such devices must be acquired in advance of a spill and stored until

needed, and in all but small spills, deployment may be difficult. In addition, material and dispersal equipment costs are a major deterrent to their use (15).

The use of foams in vapor hazard control has been demonstrated for a broad range of volatile chemicals (15). Unfortunately, it is difficult to accurately quantify the benefits of foam systems because the effects will vary as a function of the chemical spilled, foam type, spill size, and atmospheric conditions. It has been found that with some materials, foams have a net positive effects, but with others, foams may exaggerate the hazard (15).

Little or no information is available concerning the effects and results of foam systems in controlling hazardous releases from carbon tetrachloride spills. However, based on research with chemicals similar in nature to carbon tetrachloride, a net positive effect would be expected (15). The extent of the reduction in concentration of carbon tetrachloride will depend on the type of foam used. Research in this area has indicated that foams with a medium to high expansion ratio (300 to 350:1) give significantly better results than do foam with low expansion ratios (6 to 8:1) (16). The expansion ratio is the ratio of the volume of foam produced to the volume of solution fed to the foam-generating device.

Regardless of the type of foam used, the slower the foam drainage rate, the better its performance will be. A slow draining foam will spread more evenly, show more resistance to temperature and pH effects, and collapse more slowly (16). The initial cost of a slow draining foam may be higher than other foams, but a cost-effective system will be realized in superior performance (16).

4.6 OPERATION AND MAINTENANCE PRACTICES

Accidental release of toxic materials result not only from deficiencies of design, but also from deficiencies of operation. Thus, safe operation of plants using carbon tetrachloride requires competent and experienced managers and staff in addition to a well-considered and fully understood system of work.

Employees should be trained about the important aspects of handling carbon tetrachloride, including: the proper means of handling and storing, hazards resulting from improper use and handling, prevention of spills, cleanup procedures, maintenance procedures and emergency procedures. Well-defined and planned practices and procedures can minimize the possibility of a hazardous release and can also reduce the magnitude of an accidental release.

Proper maintenance and modification programs should be incorporated into plant design and operation to prevent possible hazardous releases of carbon tetrachloride.

4.7 CONTROL EFFECTIVENESS

It is difficult to quantify the control effectiveness of preventive and protective measures to reduce the probability and magnitude of accidental releases. Preventive measures, which may involve numerous combinations of process design, equipment design, and operational measures, are especially difficult to quantify because they reduce the probability rather than a physical quantity of a chemical release. Protective measures are more analogous to traditional pollution control technologies. Thus, they may be easier to quantify in terms of their efficiency in reducing a quantity of chemical that could be released.

Preventive measures reduce the probability of an accidental release by increasing the reliability of both process systems operations and equipment. Control effectiveness can thus be expressed through probabilities for both qualitative improvements and the quantitative improvements. Table 4-3 summarizes what appear to be some of the major design, equipment, and operational measures applicable to hazards identified for carbon tetrachloride in the SCAQMD. The items listed in Table 4-3 are for illustration only and do not necessarily represent a satisfactory control option for all cases. These control options appear to reduce the risk associated with an accidental

TABLE 4-3. EXAMPLES OF MAJOR PREVENTION AND PROTECTION MEASURES FOR CARBON TETRACHLORIDE RELEASES

Hazard Area	Prevention/Protection
Water contamination in carbon tetrachloride feed to chlorofluorocarbon reactor	Continuous moisture monitoring; backflow prevention
Carbon tetrachloride flow control	Redundant flow control loops; minimal overdesign of feed systems; fail-close control valves
Overheated reactor	Redundant temperature sensing and alarms
Temperature sensing and heating medium flow control	Redundant temperature sensors; interlock flow switch to shut off CCl_4 feed on loss of heating
Overpressure	Redundant pressure relief; not isolatable; adequate size; discharge not restricted
Corrosion	Inspection, maintenance, and corrosion monitoring
Overfilling	Redundant level sensing, alarms and interlocks; training of operators
Atmospheric releases from relief discharges	Emergency vapor recovery system, tank enclosures
Storage tank or line rupture	Diking; enclosure vented to vapor recovery; foams; siting away from mechanical damage; inspection and non-destructive testing

release when viewed from a broad perspective. However, there are undoubtedly specific cases where they will not be appropriate. Each case must be evaluated individually.

4.8 ILLUSTRATIVE COST ESTIMATES FOR CONTROLS

This section presents cost estimates for different levels of controls and for specific release prevention and protection measures that might be found in the SCAQMD for carbon tetrachloride.

4.8.1 Prevention and Protection Measures

Preventive measures reduce the probability of an accidental release from a process or storage facility by increasing the reliability of both process systems operations and equipment. Increasing the reliability of a system often increases the capital and annual costs associated with the improved prevention and protection measures. Table 4-4 presents the costs of some of the major design, equipment, and operational measures applicable to the primary hazards identified in Table 4-3 for carbon tetrachloride applications in the SCAQMD.

4.8.2 Levels of Control

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices as they apply to the design, construction, and operation of facilities where hazardous chemicals are used and stored. Equipment and procedures should be in accordance with applicable codes, standards, and regulations; however, additional measures can be taken to provide extra insurance against an accidental release.

The levels of control concept provides a means of assigning costs to increased levels of prevention and protection. The minimum level is referred to as the "Baseline" system, which consists of the elements required for normal safe operation and basic prevention of an accidental release of hazardous material.

TABLE 4-4. ESTIMATED TYPICAL COSTS OF MAJOR PREVENTION AND PROTECTION MEASURES FOR CARBON TETRACHLORIDE RELEASES[a]

Prevention/Protection Measure	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Continuous moisture monitoring	7,500-10,000	900-1,300
Flow control loop	4,000-6,000	500-750
Temperature sensor	250-400	30-50
Pressure relief		
- relief valve	1,000-2,000	120-250
- rupture disk	1,000-1,200	120-150
Interlock system for flow shut-off	1,500-2,000	175-250
Physical barriers		
- curbing	750-1,000	90-120
- 3 ft. retaining wall	1,500-2,000	175-250
Alarm system	250-500	30-75
Level sensor		
- liquid level gauge	1,500-2,000	175-250
- load cell	10,000-15,000	1,300-1,900
Diking (based on a 10,000 gal. tank)		
- 3 ft. high	1,200-1,500	150-175
- top of tank height, 10 ft.	7,000-7,500	850-900
Increased corrosion inspection[b]		200-400

[a]Based on a 10,000 gallon fixed carbon tetrachloride storage system and a 2,000 gallon continuous chlorofluorocarbon reactor system.
[b]Based on 10-20 hours at $20/hour.

The second level of control is "Level 1", which includes the baseline system with added modifications, such as improved materials of construction, additional controls, and generally more extensive release prevention measures. The costs associated with this level are higher than the baseline system costs.

The third level of control is "Level 2". This system incorporates both the "Baseline" and "Level 1" systems with additional modifications designed specifically for the prevention of an accidental release, such as alarm and interlock systems. The extra accidental release prevention measures incorporated into "Level 2" are reflected in its costs, which are much higher than those of the baseline system.

When comparing the costs of the various levels of control, it is important to realize that higher costs do not necessarily imply improved safety. The measures applied must be applied correctly. Inappropriate modifications or add-ons may not make a system safer. Each added control option increases the complexity of a system. In some cases, the hazards associated with the increased complexity may outweigh the benefits derived from the particular control option. Proper design and construction, along with proper operational practices are needed to ensure safe operation.

These estimates are for illustrative purposes only. It is doubtful that any specific installation would find all of the control options listed in these tables appropriate for their purposes. An actual system is likely to incorporate some items from each of the levels of control and also some control options not listed here. The purpose of these estimates is to illustrate the relationship between cost and control, not to provide an equipment check list.

Levels of control cost estimates were prepared for a 25-ton fixed carbon tetrachloride storage tank with a 10,000-gallon capacity and a chlorofluorocarbon reactor system. These systems are representative of storage and process facilities that might be found in the SCAQMD.

4.8.3 Cost Summaries

Table 4-5 summarizes the total capital and annual costs for each of the three levels of control for a carbon tetrachloride storage system and a chlorofluorocarbon reactor system. The costs presented correspond to the systems described in Tables 4-6 and 4-7. Each of the level costs include the cost of the basic system plus any controls. Specific cost information and breakdown for each level of control for both the storage and process facilities are presented in Tables 4-8 through 4-13.

4.8.4 Equipment Specifications and Detailed Costs

Equipment specifications and details of the capital cost estimates for the carbon tetrachloride storage and the chlorofluorocarbon reactor systems are presented in Tables 4-14 through 4-21.

4.8.5 Methodology

Format for Presenting Cost Estimates--

Tables are provided for control schemes associated with storage and process facilities for carbon tetrachloride showing capital, operating, and total annual costs. The tables are broken down into subsections for vessels, piping and valves, process machinery, instrumentation, and procedures and practice. Presentation of the costs in this manner allows for easy comparison of specific items, different levels, and different systems.

Capital Cost--All capital costs presented in this report are shown as total fixed capital costs. Table 4-22 defines the cost elements comprising total fixed capital as it is used here.

The computation of total fixed capital, as shown in Table 4-22, begins with the total direct cost for the system under consideration. This total direct cost is the total direct installed cost of all capital equipment comprising the system. Depending on the specific equipment item involved, the

TABLE 4-5. SUMMARY OF COST ESTIMATES OF POTENTIAL LEVELS OF CONTROL FOR CARBON TETRACHLORIDE STORAGE TANK AND CHLOROFLUOROCARBON REACTOR SYSTEMS

	Level of Control	Total Capital Cost (1986 $)	Total Annual Cost (1986 $/yr)
Carbon Tetrachloride Storage Tank; 25 ton Fixed Carbon Tetrachloride Tank With 10,000 gal Capacity	Baseline	59,000	7,600
	Level No. 1	254,000	30,000
	Level No. 2	319,000	38,000
Continuous Chlorofluorocarbon Reactor System With 2,000 gal Capacity	Baseline	111,000	15,000
	Level No. 1	353,000	43,000
	Level No. 2	432,000	54,000

TABLE 4-6. EXAMPLE OF LEVELS OF CONTROL FOR CARBON TETRACHLORIDE STORAGE TANK

Process: 25 ton fixed carbon tetrachloride storage tank (10,000 gal)

Controls	Baseline	Level No. 1	Level No. 2
Process:	None	None	None
Flow:	Single check valve on tank-process feed line.	Add second check valve.	Add a reduced-pressure device with internal air gap and relief vent to incinerator.
Temperature:	None	None	Add temperature indicator.
Pressure:	Free flow atmospheric vent.	Add conservation valve. Vent to refrigerated condenser.	Add systems disk, provide local pressure indication on space between disk and valve, vent to incinerator.
Quantity:	Local level indicator.	Add remote level indicator.	Add level alarm. Add high-low level interlock shut-off for both inlet and outlet line.
Location:	Away from traffic.	Away from traffic and other hazardous processes.	Away from traffic and other hazardous processes.
Materials of Construction:	Fiber-reinforced plastic (FRP).	Fiber-reinforced plastic (FRP).	Monel® clad carbon steel.
Vessel	Fixed roof atmospheric tank.	Fixed roof tank with internal floating roof.	Low pressure storage tank with pressure specification of 25 psig.
Piping:	Schedule 40 carbon steel.	Schedule 80 Saran®-lined carbon steel.	Schedule 80 Monel®.

(Continued)

TABLE 4-6 (Continued)

Process: 25 ton fixed carbon tetrachloride storage tank (10,000 gal)

Controls	Baseline	Level No. 1	Level No. 2
Process Machinery:	Centrifugal pump, carbon steel construction, stuffing box.	Centrifugal pump, Monel® construction, double mechanical seal.	Magnetically-coupled centrifugal pump, Monel® construction.
Enclosures:	None	Steel building.	Concrete building.
Diking	None	3 ft high.	Top of tank height, 10 ft.
Containment	None	Refrigerated condenser.	Same
Mitigation	None	Foam system.	Same

TABLE 4-7. EXAMPLE OF LEVELS OF CONTROL FOR CHLOROFLUOROCARBON REACTOR SYSTEM

Process: Chlorofluorocarbon Manufacture

Typical Operating Conditions: - Temperature: 176°F
Pressure: 100 psig

Controls	Baseline	Level No. 1	Level No. 2
Process:	Dryers on carbon tetrachloride feed line.	Improved reactor design.	Add interlock and backup cooling system.
Temperature:	Provide local temperature control.	Add redundant temperature sensors and alarms. Add remote indicator.	Add temperature switch to shut off carbon tetrachloride feed.
Pressure:	Single pressure relief valve. Vent to atmosphere.	Add redundant pressure sensors. Add second relief valve. Vent to vapor recovery system. Add remote pressure indicator.	Add system disks under relief valves and provide local and remote pressure indication on space between disk and valve.
Flow:	Provide local flow control on carbon tetrachloride feed and heating medium to reactor.	Add redundant flow control loops.	Add interlock flow switch to shut off carbon tetrachloride feed.
Quantity:	None	None	Level alarm.
Mixing:	Provide adequate mixing.	Add alarm on loss of recirculating pump	Interlock carbon tetrachloride feed on loss of mixing.
Corrosion:	Visual inspections.	Increased inspections and monitoring.	Same

(Continued)

TABLE 4-7 (Continued)

Process: Chlorofluorocarbon Manufacture

Typical Operating Conditions: - Temperature: 176°F
Pressure: 100 psig

Controls	Baseline	Level No. 1	Level No. 2
Composition:	Dryers on carbon tetrachloride feed line.	Occasional moisture monitoring of feed.	Continuous moisture monitoring of feed.
Materials of Construction:	Carbon steel.	Carbon steel with added corrosion allowance.	Monel®-clad carbon steel.
Vessel:	Pressure specification: 150 psig.	Pressure specification: 200 psig.	Pressure specification: 300 psig.
Piping:	Sch. 80 carbon steel	Sch. 80 Saran®-lined carbon steel.	Sch. 80 Monel®.
Process Machinery:	Centrifugal pump, carbon steel construction, stuffing box.	Centrifugal pump, Monel® construction, double capacity mechanical seal.	Magnetically-coupled centrifugal pump, Monel® construction.
Protective Barrier:	None	Curbing around reactor/settler.	3 ft. high retaining wall.
Enclosure:	None	Steel building.	Concrete building.
Vapor Recovery System:	None	Refrigerated condenser.	Same
Mitigation:	None	Foam system.	Same

TABLE 4-8. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE CARBON TETRACHLORIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	36,000	4,200
Piping and Valves:		
Pipework	4,500	520
Check Valves	520	60
Ball Valves (5)	3,200	370
Process Machinery:		
Centrifugal Pump	11,000	1,200
Instrumentation:		
Pressure Gauges (4)	1,500	170
Liquid Level Gauge	1,500	170
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		15
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		30
Valve Maintenance		350
Total Costs	59,000	7,600

TABLE 4-9. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 CARBON TETRACHLORIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	48,000	5,500
Piping and Valves:		
Pipework	6,200	720
Check Valves	1,100	120
Ball Valves (5)	3,200	370
Relief Valve	2,000	230
Process Machinery:		
Centrifugal Pump	25,000	3,000
Instrumentation:		
Pressure Gauges (4)	1,500	170
Flow Indicator	3,700	430
Liquid Level Gauge	1,500	170
Remote Level Indicator	1,900	220
Enclosures:		
Steel Building	10,000	1,200
Vapor Recovery System:	150,000	17,000
Diking:		
3 ft. High Concrete Diking	1,300	160
Procedures and Practices:		
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		30
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		35
Valve Maintenance		400
Total Costs	254,000	30,000

TABLE 4-10. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 CARBON TETRACHLORIDE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage Tank	64,000	7,500
Piping and Valves:		
Pipework	9,200	1,100
Check Valves	2,700	310
Ball Valves (5)	3,200	370
Relief Valve	2,000	230
Rupture Disk	600	70
Process Machinery:		
Centrifugal Pump	32,000	3,700
Instrumentation:		
Temperature Indicator	1,800	220
Pressure Gauges (6)	2,200	260
Flow Indicator	3,700	430
Load Cell	16,000	1,800
Remote Level Indicator	1,900	220
Level Alarm	740	90
High-Low Level Shutoff	1,900	220
Enclosures:		
Concrete Building	150,000	1,700
Vapor Recovery System:	150,000	17,000
Diking:		
10 ft. High Concrete Dike	7,400	870
Procedures and Practices:	7,400	
Visual Tank Inspection (external)		15
Visual Tank Inspection (internal)		60
Relief Valve Inspection		50
Piping Inspection		300
Piping Maintenance		120
Valve Inspection		35
Valve Maintenance		400
Total Costs	319,000	38,000

TABLE 4-11. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE CHLOROFLUOROCARBON REACTOR SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Reactor and Feed Dryer	63,000	7,600
Piping and Valves:		
Pipework	6,800	800
Ball Valves (8)	5,000	600
Relief Valve	2,000	230
Process Machinery:		
Centrifugal Pumps (2)	20,000	2,400
Instrumentation:		
Pressure Gauges (3)	1,100	129
Local Temperature Indicator	1,800	220
Flow Control Loop (2)	11,000	1,300
Maintenance and Inspections:		
Visual Tower Inspection (external)		15
Visual Tower Inspection (internal)		60
Piping Inspection		900
Piping Maintenance		360
Valve Inspection		30
Valve Maintenance		350
Total Costs	111,000	15,000

TABLE 4-12. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 CHLOROFLUOROCARBON REACTOR SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Reactor and Dryers	84,000	10,000
Piping and Valves:		
Pipework	28,000	3,300
Ball Valves (8)	5,000	600
Relief Valves (2)	4,000	450
Process Machinery:		
Centrifugal Pumps (2)	49,000	5,900
Instrumentation:		
Pressure Gauges (3)	1,100	130
Local Temperature Indicator	1,200	220
Temperature Sensor	360	45
Temperature Alarm	360	45
Flow Control Loops (4)	22,000	2,600
Moisture Alarm	360	45
Diking:		
Curbing Around Tower	1,200	150
Enclosure:		
Steel Building	10,000	1,200
Vapor Recovery System:	145,000	17,000
Maintenance and Inspections:		
Visual Tower Inspection (external)		15
Visual Tower Inspection (internal)		60
Piping Inspection		900
Piping Maintenance		360
Valve Inspection		30
Valve Maintenance		350
Total Costs	353,000	43,000

TABLE 4-13. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 CHLOROFLUOROCARBON REACTOR SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Equipment:		
Reactor and Dryers	115,000	14,000
Piping and Valves:		
Pipework	40,000	4,800
Ball Valves (8)	5,000	600
Relief Valves (2)	4,000	470
Rupture Disks (2)	1,200	140
Process Machinery:		
Centrifugal Pumps (2)	62,000	8,000
Instrumentation:		
Pressure Gauges (3)	1,100	130
Level Alarm	360	45
Local Temperature Indicator	1,800	220
Remote Temperature Indicator	1,800	220
Temperature Sensor	360	45
Temperature Alarm	360	45
Temperature Switch	540	65
Flow Interlock System	1,800	220
Flow Control Loops (4)	22,000	2,600
Moisture Alarm	360	45
Moisture Monitoring System	9,000	1,100
Diking:		
0.9m (3 ft.) High Retaining Wall	3,000	360
Enclosure:		
Concrete Building	18,000	2,200
Vapor Recovery System:	144,000	17,000
Maintenance and Inspections:		
Visual Tower Inspection (external)		15
Visual Tower Inspection (internal)		60
Piping Inspection		900
Piping Maintenance		360
Valve Inspection		30
Valve Maintenance		350
Total Costs	432,000	54,000

TABLE 4-14. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH CARBON TETRACHLORIDE STORAGE SYSTEM

Equipment Item	Equipment Specification	Reference
VESSELS:		
Storage Tank	Baseline: 10,000 gal carbon steel fixed roof atmospheric tank.	14,17,18, 19,20
	Level #1: 10,000 gal fiberglass-reinforced plastic fixed roof tank with floating roof.	
	Level #2: 10,000 gal Monel®-clad carbon steel tank.	
PIPING AND VALVES:		
Pipework	Baseline: 100 ft of 4-in Schedule 40 carbon steel.	21
	Level #1: 4-in Schedule 40 Saran®-lined carbon steel	
	Level #2: 4-in Schedule 80 Monel®.	
Check valve	4-in vertical lift check valve, Monel® trim.	18,22
Ball valve	4-in Class 300, flanged, Monel® ball and stem.	17,18
Relief valve	1-in x 2-in Class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, Monel® trim.	18
Reduced pressure device	Double check valve type device with internal air gap and relief valve.	17
Process Machinery	Baseline: Single stage, carbon steel construction, stuffing box, 100 gpm capacity.	18,23
	Level #1: Single stage, Monel® construction, double mechanical seal.	

(Continued)

TABLE 4-14 (Continued)

Equipment Item	Equipment Specification	Reference
	Level 2: Monel® construction, magnetically-coupled, 100 gpm capacity.	18,23
INSTRUMENTATION:		
Temperature indicator	Thermocouple, thermowell, electronic indicator.	17,18,24
Pressure gauge	Diaphragm sealed, Monel® diaphragm, 0-1,000 psi.	17,18,24
Flow indicator	Differential pressure cell, transmitter, and associated flowmeter.	17,24
Liquid level gauge	Differential pressure type level gauge.	17,24
Load cell	Electrically operated load cell with electronic indicator.	17,24,25
Level alarm	Indicating and audible alarm.	18,26,27
High-low level shutoff	Solenoid valve, switch, and relay system.	17,18,24, 26
ENCLOSURES:		
Building	Level #1: 26 gauge steel walls and roof, door, ventilation system.	26
	Level #2: 10-in concrete walls, 26 gauge steel roof, door.	
DIKING:	Level #1: 6-in concrete walls, 3 ft high.	26
	Level #2: 10-in concrete walls, top of tank height, 10 ft.	
VAPOR RECOVERY SYSTEM:	Level 1 and 2: 2 ton refrigeration, 100 ft^2 condensor, vapor recovery system.	14,28

TABLE 4-15. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE CARBON TETRACHLORIDE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs (1986 $)	Indirect Costs	Capital Cost
VESSELS:					
Storage Tank	16,000	8,000	24,000	8,400	36,000
PIPING AND VALVES:					
Pipework	900	2,100	3,000	1,100	4,500
Check Valves	320	30	350	120	520
Ball Valves (5)	2,000	150	2,150	750	3,200
PROCESS MACHINERY:					
Centrifugal Pump	4,900	2,100	7,000	2,500	11,000
INSTRUMENTATION:					
Pressure Gauges (4)	800	200	1,000	350	1,500
Liquid Level Gauge	800	200	1,000	350	1,500
Total Costs	26,000	13,000	39,000	14,000	58,000

TABLE 4-16. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 CARBON TETRACHLORIDE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
VESSELS:					
Storage Tank	22,000	10,000	32,000	11,000	48,000
PIPING AND VALVES:					
Pipework	3,300	860	4,160	1,500	6,200
Check Valves	640	60	700	250	1,100
Ball Valves (5)	2,000	150	2,150	750	3,200
Relief Valve	1,300	50	1,350	460	2,000
PROCESS MACHINERY:					
Centrifugal Pump	12,000	5,000	17,000	6,000	25,000
INSTRUMENTATION:					
Pressure Gauges (4)	800	200	1,000	350	1,500
Flow Indicator	2,000	500	2,500	880	3,700
Liquid Level Gauge	800	200	1,000	350	1,500
Remote Level Indicator	1,000	250	1,250	430	1,900
ENCLOSURES:					
Steel Building	4,600	2,300	6,900	2,400	10,000
VAPOR RECOVERY SYSTEM:	70,000	30,000	100,000	35,000	150,000
DIKING:					
3 ft. High Concrete Diking	390	510	900	320	1,300
Total Costs	121,000	50,000	171,000	60,000	254,000

TABLE 4-17. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 CARBON TETRACHLORIDE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
VESSELS:					
Storage Tank	30,000	13,000	43,000	15,000	64 000
PIPING AND VALVES:					
Pipework	4,800	1,400	6,200	2,200	9,200
Reduced Pressure Device	1,600	200	1,800	630	2,700
Ball Valves (5)	2,000	150	2,150	750	3,200
Relief Valve	1,300	50	1,350	460	2,000
Rupture Disk	350	50	400	140	600
PROCESS MACHINERY:					
Centrifugal Pump	15,000	6,400	21,400	7,500	32,000
INSTRUMENTATION:					
Temperature Indicator	1,000	250	1,250	310	1,800
Pressure Gauges (6)	1,200	300	1,500	530	2,200
Flow Indicator	2,000	500	2,500	880	3,700
Load Cell	8,400	2,100	10,500	3,700	16,000
Remote Level Indicator	1,000	250	1,250	440	1,900
Level Alarm	400	100	500	180	740
High-Low Level Shutoff	1,000	250	1,250	440	1,900
ENCLOSURES:					
Concrete Building	6,100	6,600	12,700	4,500	19,000
VAPOR RECOVERY SYSTEM:	70,000	30,000	100,000	35,000	150,000
DIKING:					
10 ft High Concrete Dike	2,200	2,800	5,000	1,800	7,400
Total Costs	149,000	65,000	214,000	75,000	319,000

TABLE 4-18. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH CHLOROFLUOROCARBON STORAGE SYSTEM

Equipment Item	Equipment Specification	Reference
VESSELS:		
Reactor	2,000 gal continuous reactor system including system catalyst	17
Feed Dryers	Sieve dryers or equivalent on carbon tetrachloride feed stream	17
PIPING AND VALVES:	Baseline: 300 ft of 4 in Schedule 80 carbon steel	21
Pipework	Level 1: 4-in Schedule 80 Saran®-lined carbon steel	
	Level 2: 4-in Schedule 80 Monel®	
Ball valves	4-in Class 300, flanged, carbon steel construction	17,18
Relief valves	2-in x 3-in Class 300 inlet and outlet flange angle body, closed bonnet with screwed cap, carbon steel body, Monel® trim	18
Rupture disk	2-in Monel® disk and carbon steel holder	24,29
PROCESS MACHINERY:	Baseline: Single stage, carbon steel construction, stuffing box	
Centrifugal pump	Level 1: Single stage, Monel® construction, double mechanical seal	18,23
	Level 2: Monel® construction, magnetically-coupled	18,23
INSTRUMENTATION:		
Temperature sensor	Thermocouple and associated thermowell	17,18,24
Temperature alarm	Indicating and audible alarm	18,26,27
Temperature switch	Two-stage switch with independently set actuation	17,24

(Continued)

TABLE 4-18 (Continued)

Equipment Item	Equipment Specification	Reference
Remote temperature indicator	Transmitter and associated electronic indicator	17,24
Remote pressure indicator	Transducer, transmitter and electronic indicator	17,24
Pressure guage	Diaphragm sealed, Hastelloy C diaphragm, 0-1,000 psi	17,18,24
Flow control loop	4-in globe control valve, Monel® trim, flowmeter and PID controller	17,24
Flow interlock system	Solenoid valve, switch, and relay system	17,18,24, 26
Level alarm	Indicating and audible alarm	18,26,27
Moisture monitoring system	Capacitance or infrared absorption system	25
DIKING:	Level 1: 6-in high concrete curbing	26
	Level 2: 3-ft high concrete retaining wall	
VAPOR RECOVERY SYSTEM:	Level 1 and 2: 2-ton refrigeration, 100-ft^2 condensor, vapor recovery system.	14,28

TABLE 4-19. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE CHLOROFLUOROCARBON REACTOR SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
EQUIPMENT:					
Reactor and Feed Dryer	30,000	14,000	44,000	11,000	63,000
PIPING AND VALVES:					
Pipework	1,700	3,000	4,700	1,200	6,800
Ball Valves (8)	3,200	300	3,500	880	5,000
Relief Valve	1,300	50	1,350	340	2,000
PROCESS MACHINERY:					
Centrifugal Pumps (2)	10,000	4,000	14,000	3,500	20,000
INSTRUMENTATION:					
Pressure Gauges (3)	600	150	750	190	1,100
Local Temperature Indicator	1,000	250	1,250	310	1,800
Flow Control Loop (2)	6,000	1,500	7,500	1,900	11,000
Total Costs	54,000	23,000	77,000	20,000	111,000

TABLE 4-20. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 CHLOROFLUOROCARBON REACTOR SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
EQUIPMENT:					
Reactor and Dryers	40,000	18,000	58,000	15,000	84,000
PIPING AND VALVES:					
Pipework	15,000	4,000	19,000	4,800	28,000
Ball Valves (8)	3,200	300	3,500	880	5,000
Relief Valves (2)	2,600	100	2,700	680	4,000
PROCESS MACHINERY:					
Centrifugal Pumps (2)	24,000	10,000	34,000	8,500	49,000
INSTRUMENTATION:					
Pressure Gauges (3)	600	150	750	190	1,100
Local Temperature Indicator	1,000	250	1,250	310	1,800
Temperature Sensor	200	50	250	60	360
Temperature Alarm	200	50	250	60	360
Flow Control Loops (4)	12,000	3,000	15,000	3,800	22,000
Moisture Alarm	200	50	250	60	360
DIKING:					
Curbing Around Tower	500	350	850	210	1,200
ENCLOSURE:					
Steel Building	4,600	2,300	6,900	1,700	10,000
VAPOR RECOVERY SYSTEM:	70,000	30,000	100,000	25,000	145,000
Total Costs	174,000	69,000	243,000	62,000	353,000

TABLE 4-21. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 CHLOROFLUOROCARBON REACTOR SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
EQUIPMENT:					
Reactor and Dryers	55,000	25,000	80,000	20,000	115,000
PIPING AND VALVES:					
Pipework	22,000	6,000	28,000	7,000	40,000
Ball Valves (8)	3,200	300	3,500	880	5,000
Relief Valves (2)	2,600	100	2,700	680	4,000
Rupture Disks (2)	700	100	800	200	1,200
PROCESS MACHINERY:					
Centrifugal Pumps (2)	30,000	12,800	42,800	11,000	62,000
INSTRUMENTATION:					
Pressure Gauges (3)	600	150	750	190	1,100
Level Alarm	200	50	250	60	360
Local Temperature Indicator	1,000	250	1,250	310	1,800
Remote Temperature Indicator	1,000	250	1,250	310	1,800
Temperature Sensor	200	50	250	60	360
Temperature Alarm	200	50	250	60	360
Temperature Switch	300	75	375	95	540
Flow Interlock System	1,000	250	1,250	310	1,800
Flow Control Loops (4))	12,000	3,000	15,000	3,800	22,000
Moisture Alarm	200	50	250	60	360
Moisture Monitoring System	5,000	1,250	6,250	1,600	9,000
DIKING:					
3 ft High Retaining Wall	900	1,200	2,100	530	3,000

(Continued)

TABLE 4-21 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
ENCLOSURE:					
Concrete Building	6,000	6,600	12,600	3,200	18,000
VAPOR RECOVERY SYSTEM:	70,000	30,000	100,000	25,000	144,000
Total Costs	212,000	88,000	300,000	75,000	432,000

TABLE 4-22. FORMAT FOR TOTAL FIXED CAPITAL COST

Item No.	Item	Cost
1	Total Material Cost	-
2	Total Labor Cost	-
3	Total Direct Cost	Items 1 + 2
4	Indirect Cost Items (Engineering & Construction Expenses)	0.35 x Item 3[a]
5	Total Bare Module Cost	Items (3 + 4)
6	Contingency	(0.05 x Item 5)[b]
7	Contractor's Fee	0.05 x Item 5
8	Total Fixed Capital Cost	Items (5 + 6 + 7)

[a] For storage facilities, the indirect cost factor is 0.35. For process facilities, the indirect cost factor is 0.25.

[b] For storage facilities, the contingency cost factor is 0.05. For process facilities, the contingency cost factor is 0.10.

direct capital cost was available or was derived from uninstalled costs by computing costs of installation separately. To obtain the total fixed capital cost, other costs obtained by using factors are added to the total fixed direct costs.

The first group of other cost elements is indirect costs. These include engineering and supervision, construction expenses, and various other expenses such as administration expenses. These costs are computed by multiplying total direct costs by a factor shown in Table 4-22. The factor is approximate, is obtained from the cost literature, and is based on previous experience with capital projects of a similar nature. Factors can have a range of values and vary according to technology area and for individual technologies within an area. Based on judgement and experience, appropriate factors were selected for use in this report.

The sum of indirect costs and total direct costs equals total bare module cost. Some additional cost elements such as contractor's fee and contingency, are calculated by applying and adding appropriate factors to the total bare module cost, as shown in Table 4-22, to obtain the total fixed capital cost.

Annual Cost--Annual costs are obtained for each equipment item by applying a factor for both capital recovery and for maintenance expenses to the direct cost of each equipment item. Table 4-23 defines the cost elements and the appropriate factors comprising these costs. Additional annual costs are incurred for procedural items such as valve and vessel inspections, for example. The sum of these individual costs equals the total annual cost.

Sources of Information--

The costs presented in this report are derived from cost information in existing published sources and also from recent vendor information. The objective of this effort was to present cost levels for carbon tetrachloride process and storage facilities using the best costs for available sources. The primary sources of cost information are Peters and Timmerhaus (17), Chemical Engineering (30), and Valle-Riestra (31), supplemented by other

TABLE 4-23. FORMAT FOR TOTAL ANNUAL COST

Item No.	Item	Cost
1	Total Direct Cost	-
2	Capital Recovery on Equipment Items	0.163 x Item 1
3	Maintenance Expense on Equipment Items	0.01 x Item 1
4	Total Procedural Items	-
5	Total Annual Cost	Items (2 + 3 + 4)

sources and references where necessary. Adjustments were made to update all costs to June 1986 dollars. For some equipment items, well-documented costs were not available; these had to be developed from component costs.

Costs in this document reflect the "typical" or "average" costs for specific equipment items. This restricts the use of data in this report to:

- Preliminary estimates used for policy planning;
- Comparison of relative costs of different levels or systems; and
- Approximations of costs that might be incurred for a specific application.

Costs in this report are considered to be "order of magnitude" with a ±50 percent margin because they are based on preliminary estimates and many are updated from literature sources. Large departures from the design basis of a particular system presented in this manual or the advent of a different technology might cause the system cost to vary more than this. If used as intended, however, this document will provide a reasonable source of preliminary cost information for the facilities covered.

When comparing costs in this manual to those from other references, the user should be sure the design bases are comparable and that the capital and annual costs as defined here are the same.

Cost Updating--

All costs in this report are expressed in June 1986 dollars. Costs reported in the literature were updated using cost indices for materials and labor.

Costs expressed in base-year dollars may be adjusted to dollars for another year by applying cost indices as shown in the following equation:

$$\text{new base-year cost} = \text{old base-year cost} \times \frac{\text{new base year index}}{\text{old base year index}}$$

The Chemical Engineering (CE) Plant Cost Index was used to update costs for this report. For June 1986, the index is 316.3.

Equipment Costs--

Most of the equipment costs presented in this manual were obtained directly from literature sources of vendor information and correspond to a specific design standard. Special cost estimating techniques, however, were used in determining the costs associated with vessels, piping systems, vapor recovery systems, diking, and enclosures. The techniques are presented in the following subsections of this manual.

Vessels--The total purchased cost for a vessel, as dollars per pound of weight of fabricated unit free on board (f.o.b.) with carbon steel as the basis (January 1979 dollars) were determined using the following equation from Peters and Timmerhaus (17):

$$\text{Cost} = [50\ (\text{Weight of Vessel in Pounds})^{-0.34}]\ [\text{Weight of Vessel in Pounds}]$$

The vessel weight is determined using appropriate design equations, as given by Peters and Timmerhaus (17) that allow for wall thickness adjustments for corrosion allowances, for example. The vessel weight is increased by a factor of 0.15 for horizontal vessels and 0.20 for vertical vessels to account for the added weight of nozzles, manholes, and skirts or saddles. Appropriate factors are applied for different materials of construction as given in Peters and Timmerhaus (17). Vessel costs are updated using cost factors. Finally, a shipping cost amounting to 10 percent of the purchased cost is added to obtain the delivered equipment cost.

Piping--Piping costs were obtained from cost information and data presented by Yamartino (21). The simplified approach used assumes that a certain length of piping containing a given number of valves, flanges, and fittings is contained in the storage or process facility. The data presented by Yamartino (21) permit cost determinations for various lengths, sizes, and types of piping systems. Using these factors, a representative estimate can be obtained for each of the storage and process facilities.

Diking--Diking costs were estimated using Mean's Manual (26) for reinforced concrete walls. The following assumptions were made to determine the costs. The dike contains the entire contents of a tank in the event of a leak or release. Two dike sizes are possible: a three-foot high dike, six-inches thick, and a top-of-tank height dike ten inches thick. The tanks are raised off the ground and are not volumetrically included in the volume enclosed by the diking. These assumptions facilitate cost determination for any size diking system.

Enclosures--Enclosure costs were estimated using Mean's Manual (26) for both reinforced concrete and steel-walled buildings. The buildings are assumed to enclose the same area and volume as the top-of-tank height dikes. The concrete building is ten-inches thick with a 26-gauge steel roof and a metal door. The steel building has 26 gauge roofing and siding and metal door. The cost of a ventilation system was determined using a typical 1,000 scfm unit and doubling the cost to account for duct work and requirements for the safe enclosure of hazardous chemicals.

Vapor Recovery Systems--A refrigerated condenser system cost was estimated using a technique developed by Vatavuk and Neveril (28) based on the amount of refrigeration required for a given situation. The refrigeration and condenser area requirements were obtained from reference (14) based on a given storage facility.

Installation Factors--

Installation costs were developed for all equipment items included in both the process and storage systems. The costs include both the material and labor costs for installation of a particular piece of equipment. Costs were obtained directly from literature sources and vendor information or indirectly by assuming a certain percentage of the purchased equipment cost by using estimating factors obtained from Peters and Timmerhaus (17) and Valle-Riestra (31). Table 4-24 lists the cost factors used or the reference from which the cost was obtained directly. Many of the costs obtained from the literature were updated to June 1986 dollars using a 10 percent per year rate of increase for labor and cost indices for materials associated with installation.

TABLE 4-24. FORMAT FOR INSTALLATION COSTS

Equipment Item	Factor or Reference
Vessels:	
Storage Tank	0.45
Piping and Valves:	
Pipework	Ref. 21
Reduced Pressure Device	Ref. 18
Check Valves	Ref. 18
Gate Valves	Ref. 18
Ball Valves	Ref. 18
Relief Valves	Ref. 18
Rupture Disks	Ref. 18
Process Machinery:	
Centrifugal Pump	0.43
Gear Pump	0.43
Instrumentation:	
All Instrumentation Items	0.25
Enclosures:	Ref. 26
Diking:	Ref. 26
Vapor Recovery:	0.45

SECTION 5

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APPENDIX A
GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and/or results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Assessment: The process whereby the hazards which have been identified are evaluated in order to provide an estimate for the level of risk.

Cavitation: The formation and collapse of vapor bubbles in a flowing liquid. Specifically the formation and collapse of vapor cavities in a pump when there is sufficient resistance to flow at the inlet side.

Containment/control: A system to which toxic emissions from safety relief discharges are routed to be controlled. A caustic scrubber and/or flare can be containment/control devices. These systems may serve the dual function of destructing continuous process exhaust gas emissions.

Creep failure: Failure of a piece of metal as a result of creep. Creep is time dependent deformation as a result of stress. Metals will deform when exposed to stress. High levels of stress can result in rapid deformation and rapid failure. Lower levels of stress can result in slow deformation and protracted failure.

Deadheading: Closing or nearly closing or blocking the discharge outlet or piping of an operating pump or compressor.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Hygroscopic: Readily absorbing and retaining moisture, usually in reference to readily absorbing moisture from the air.

Identification: The recognition of a situation, its causes and consequences relating to a defined potential, e.g. Hazard Identification.

Mild steel: Carbon steel containing a maximum of about 0.25% carbon. Mild steel is satisfactory for use where severe corrodants are not encountered or where protective coatings can be used to prevent or reduce corrosion rates to acceptable levels.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Passivation film: A layer of oxide or other chemical compound of a metal on its surface that acts as a protective barrier against corrosion or further chemical reaction.

Plant: A location at which a process or set of processes are used to produce, refine, or repackage, chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Primary Containment: The containment provided by the piping, vessels and machinery used in a facility for handling chemicals under normal operating conditions.

Probability/potential: A measure, either qualitative or quantitative, that an event will occur within some unit of time.

Process: The sequence of physical and chemical operations for the production, refining, repackaging or storage of chemicals.

Process machinery: Process equipment, such as pumps, compressors, heaters, or agitators, that would not be categorized as piping or vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Qualitative Evaluation: Assessing the risk of an accidental release at a facility in relative terms; the end result of the assessment being a verbal description of the risk.

Quantitative Evaluation: Assessing the risk of an accidental release at a facility in numerical terms; the end result of the assessment being some type of number reflects risk, such as faults per year or mean time between failure.

Reactivity: The ability of one chemical to undergo a chemical reaction with another chemical. Reactivity of one chemical is always measured in reference to the potential for reaction with itself or with another chemical. A chemical is sometimes said to be "reactive", or have high "reactivity", without reference to another chemical. Usually this means that the chemical has the ability to react with common materials such as water, or common materials of construction such as carbon steel.

Redundancy: For control systems, redundancy is the presence of a second piece of control equipment where only one would be required. The second piece of equipment is installed to act as a backup in the event that the primary piece of equipment fails. Redundant equipment can be installed to backup all or selected portions of a control system.

Risk: The probability that a hazard may be realized at any specified level in a given span of time.

Secondary Containment: Process equipment specifically designed to contain material that has breached primary containment before the material is released to the environment and becomes an accidental release. A vent duct and scrubber that are attached to the outlet of a pressure relief device are examples of secondary containment.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX B

TABLE B-1. METRIC (SI) CONVERSION FACTORS

Quantity	To Convert From	To	Multiply By
Length:	in	cm	2.54
	ft	m	0.3048
Area:	in^2	cm^2	6.4516
	ft^2	m^2	0.0929
Volume:	in^3	cm^3	16.39
	ft^3	m^3	0.0283
	gal	m^3	0.0038
Mass (weight):	lb	kg	0.4536
	short ton (ton)	Mg	0.9072
	short ton (ton)	metric ton (t)	0.9072
Pressure:	atm	kPa	101.3
	mm Hg	kPa	0.133
	psia	kPa	6.895
	psig	kPa*	(psig+14.696)x(6.895)
Temperature:	°F	°C*	(5/9)x(°F-32)
	°C	K*	°C+273.15
Caloric Value;	Btu/lb	kJ/kg	2.326
Enthalpy:	Btu/lbmol	kJ/kgmol	2.326
	kcal/gmol	kJ/kgmol	4.184
Specific-Heat Capacity:	Btu/lb-°F	kJ/kg-°C	4.1868
Density:	lb/ft^3	kg/m^3	16.02
	lb/gal	kg/m^3	119.8
Concentration:	oz/gal	kg/m^3	
	quarts/gal	cm^3/m^3	25,000
Flowrate:	gal/min	m^3/min	0.0038
	gal/day	m^3/day	0.0038
	ft^3/min	m^3/min	0.0283
Velocity:	ft/min	m/min	0.3048
	ft/sec	m/sec	0.3048
Viscosity:	centipoise (CP)	kg/m-s	0.001

*Calculate as indicated

END